

Higgs Physics studies at the Muon Collider

WORKING NOTE

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The Higgs particle, if it exists, would help our understanding of electroweak symmetry breaking, fermion and gauge boson mass generation and hierarchy. CDF and D0 at the Tevatron have stringent limits on the Higgs mass. CMS and Atlas experiments at LHC should soon be able to discover or rule out the Higgs particle with 125 GeV mass. The best place to study the Standard Model or Supersymmetry Higgs particles, if they exist, may be the Muon Collider.

PACS numbers:

I. INTRODUCTION

The Higgs particle, if it exists, would help our understanding of electroweak symmetry breaking, fermion and gauge boson mass generation and hierarchy. CDF and D0 at the Tevatron have stringent limits on the Higgs mass. CMS and Atlas experiments at LHC should soon be able to discover or rule out Higgs particle with 125 GeV mass.

The Muon Collider has several significant advantages: 1) s-channel Higgs production : The $\ell^+\ell^- \rightarrow h$ s-channel production rate is proportional to m_ℓ^2 , so that the production cross section at the Muon Collider is 40,000 times higher than the ILC or CLIC. 2) The high precision fixed beam energy of the Muon Collider provides important information about the incoming muons and kinematic constraints for the physics analysis. Because of the heavier mass of muons relative to electrons, the Muon Collider has significantly less beamstrahlung and beam-beam effects than ILC or CLIC. The narrow beam energy spread at the Muon Collider may enable precision measurements of the mass of the Higgs particle(s). 3) In comparison to ILC or CLIC, the circular Muon Collider naturally allows multiple interaction points with 2 (or more) detectors, which essentially increase the effective luminosity. The best place to study the Standard Model or Supersymmetry Higgs particles if they exist, may be the Muon Collider.

To study the physics of the Higgs particle which may be discovered soon at CMS and Atlas, We first study the s-channel h production $\mu^+\mu^- \rightarrow h$ decaying into $\rightarrow b\bar{b}$ or $\rightarrow W^+W^-$. We also explore $\mu^+\mu^- \rightarrow H^0, A^0, Zh$ productions and background processes. We first study for the Muon Collider at the Generator level using Pythia.

In the future: 1) Study $\mu^+\mu^- \rightarrow h^0, H^0, A^0$ with Pythia and with full detector simulation. 2) Study charginos and neutralinos with $\mu^+\mu^- \rightarrow h^0, H^0, A^0 \rightarrow \chi\bar{\chi}$

II. SIMULATION

Pythia 6.4

We first generate/study $\mu^+\mu^- \rightarrow h^0$ with two decay modes: $h^0 \rightarrow b\bar{b}$ and $h^0 \rightarrow W^+W^-$ and background $\mu^+\mu^- \rightarrow Z^0$ at $\sqrt{s} = 125$ GeV.

III. HIGGS PRODUCTION

In the Pythia event generation, we can generate the $\mu^+\mu^-$ center-of-mass energy according to the beam energy spread of the Muon Collider. Figure 1 shows examples of energies generated for $\mu^+\mu^- \rightarrow h$ events, 1 or 2 sigma below or above M_h , with beam energy spread of 0.003%.

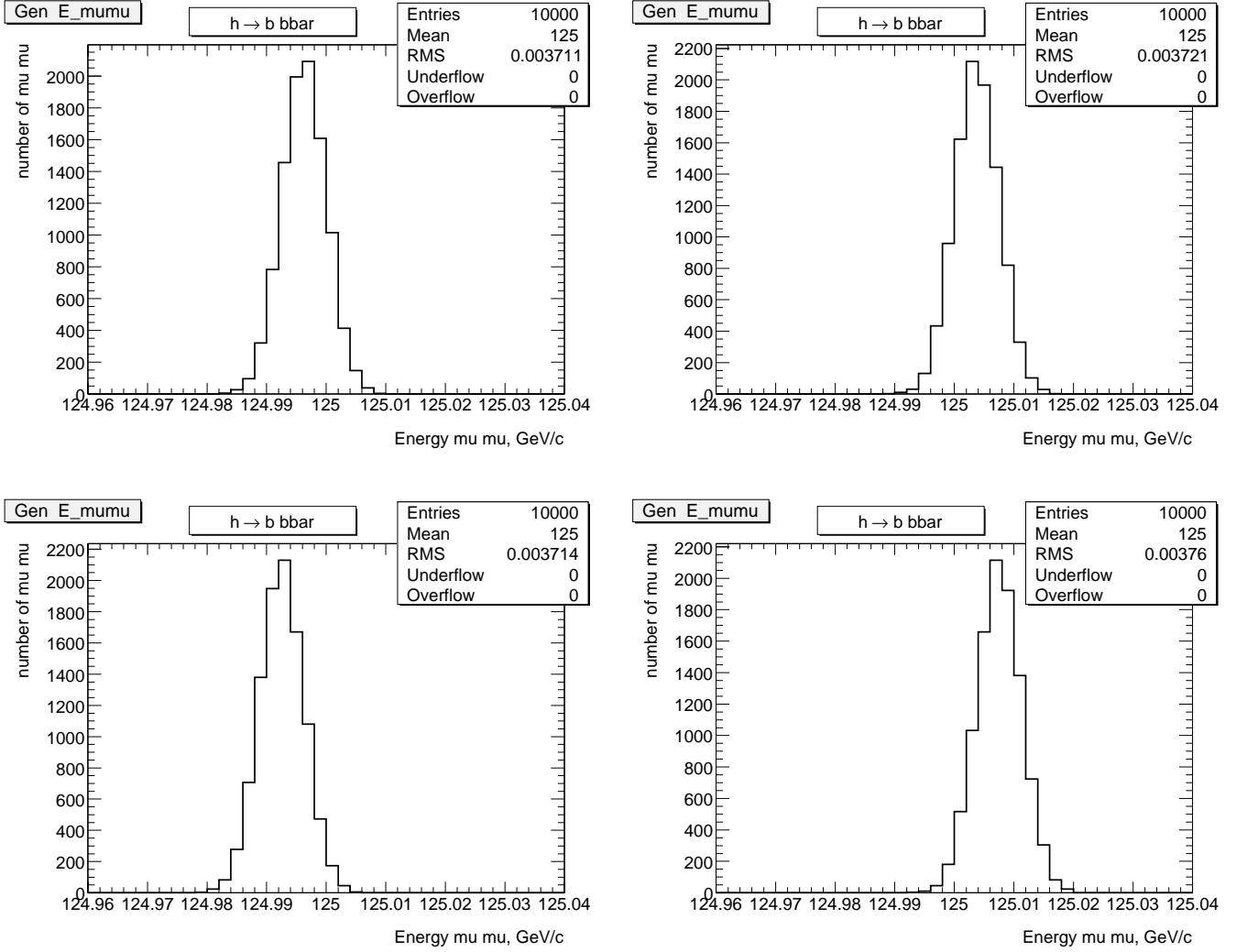


FIG. 1: Examples of other Energies generated for $\mu^+\mu^- \rightarrow h$ events, 1 or 2 sigma below or above M_h

Table I shows a comparison of cross sections and numbers of events expected in 1999 publication by Ankenbrandt et al Reference [4] and Pythia generated (2012) $\mu^+\mu^- \rightarrow h$ events. The Pythia events generated beam energy spread of 0.03% , 0.01% , 0.003% , and 0.001% show that the $\mu^+\mu^- \rightarrow h$ cross section and number of events decrease significantly for beam energy spread $\geq 0.003\%$. Table II shows $\mu^+\mu^- \rightarrow h$ peak cross sections at energies of $M_h + 1\sigma, 2\sigma, 3\sigma$ for beam energy spread of 0.001% , 0.003% , 0.01% , 0.03% , and 0.1%. The energy, mass, and width of the Higgs particle generated are shown in Figure 2, along with the $\mu^+\mu^- \rightarrow Z$ background. Because the width of the Higgs particle Γ_h is 4 MeV for $M_h = 125$ GeV, the beam energy spread needs to be $\approx 0.003\%$, which is possible according to David Neuffer and Vladimir Shiltsev.

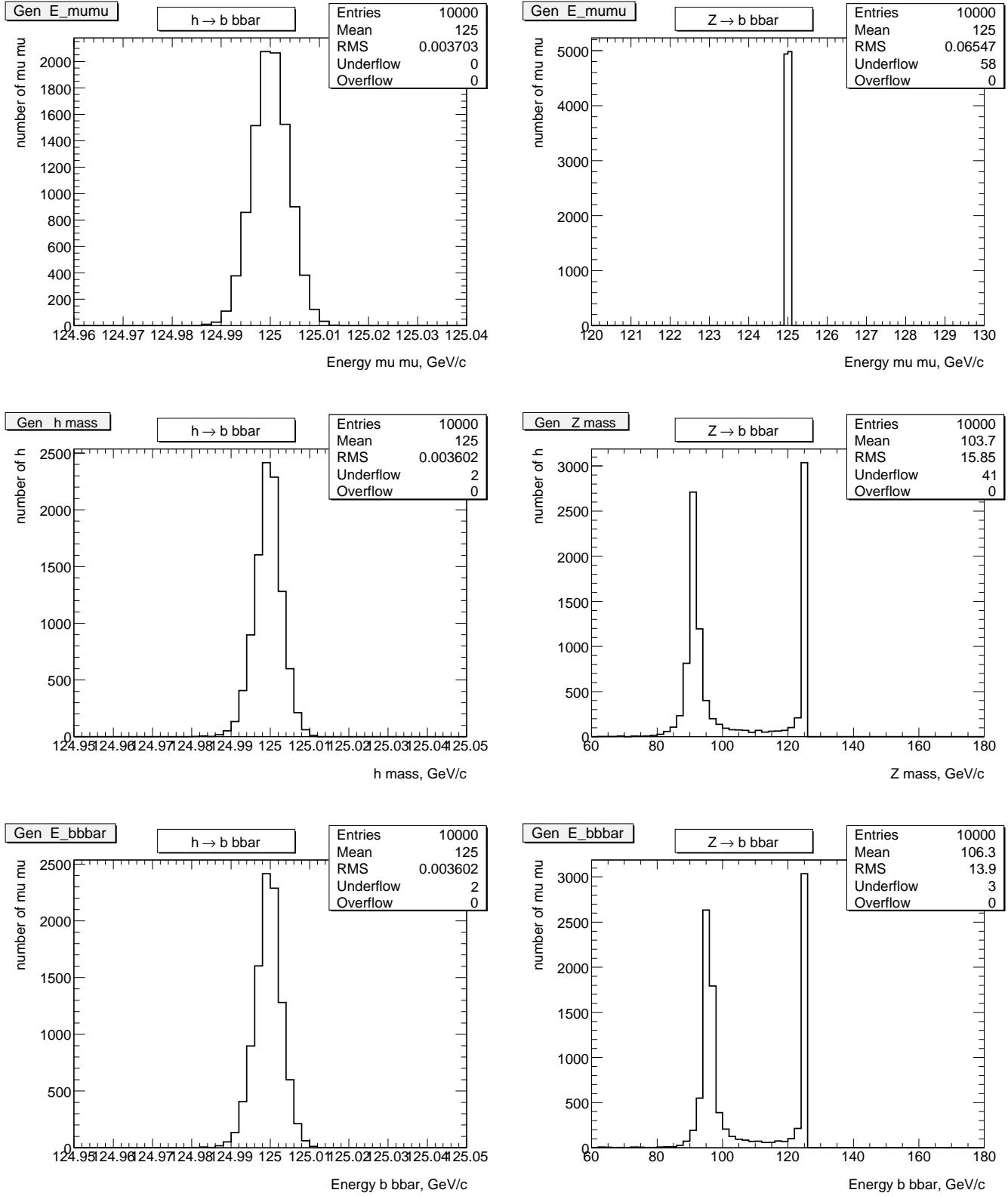
$$\mu^+\mu^- \rightarrow h$$

$\mu^+\mu^- \rightarrow h$						
1999						
rms $\Delta p/p$ (%)	0.12	0.01	0.003	5×10^4	2012	2012
\sqrt{s}		$\sigma(fb)$			$\sigma(fb)$	
100					1.9×10^3	1.4×10^4
+ 0.5 σ					2.7×10^3	1.4×10^4
+ 1.0 σ					2.3×10^3	1.1×10^4
125				2.3×10^2	1.4×10^3	1.0×10^4
+ 0.5 σ					2.0×10^3	1.0×10^4
+ 1.0 σ					1.6×10^3	7.8×10^3
Luminosity ($\text{cm}^{-2}\text{s}^{-1}$)	1.2×10^{32}	2.2×10^{31}	10^{31}		2.2×10^{31}	10^{31}
\sqrt{s}		Higgs/yr			Higgs/yr	
100	1.9×10^3	4×10^3	3.9×10^3		4.2×10^2	1.4×10^3
+ 0.5 σ					5.9×10^2	1.4×10^3
+ 1.0 σ					5.1×10^2	1.1×10^3
125					3.1×10^2	1.0×10^3
+ 0.5 σ					4.4×10^2	1.0×10^3
+ 1.0 σ					3.5×10^2	7.8×10^2

TABLE I: $\mu^+\mu^- \rightarrow h$ cross sections, and Higgs/yr for 10^7 sec/year

$\mu^+\mu^- \rightarrow h$ Peak Cross sections (fb)						
M_h GeV	rms $\Delta P/P$	M_H Peak	$M_H + 1\sigma$	$M_H + 2\sigma$	$M_H + 3\sigma$	
100	0.001%	9.2×10^4	5.6×10^4	2.7×10^4	1.6×10^4	
	0.003%		1.6×10^4	6.2×10^3	3.6×10^3	
	0.01%		3.2×10^3	1.4×10^3	8.9×10^2	
	0.03%		8.9×10^2	4.2×10^2	2.7×10^2	
	0.1%		2.5×10^2	1.3×10^2	8.1×10^1	
125	0.001%	4.3×10^4	3.1×10^4	1.8×10^4	1.1×10^4	
	0.003%		1.1×10^4	4.4×10^3	2.5×10^3	
	0.01%		2.2×10^3	9.6×10^2	5.8×10^2	
	0.03%		5.8×10^2	2.8×10^2	1.8×10^2	
	0.1%		1.7×10^2	7.9×10^1	5.3×10^1	

TABLE II: $\mu^+\mu^- \rightarrow h$ peak cross sections.

FIG. 2: Energy and mass generated for h , Z events

We also show $\ell^+\ell^- \rightarrow h$, Zh , $\nu\bar{\nu}h^0$, $\ell^+\ell^-h^0$ cross section in Tables III, IV, V.

3	$\ell^+\ell^- \rightarrow h$	
	$\sigma (fb)$	
\sqrt{s}	e^+e^-	$\mu^+\mu^-$
120	0.736	52200
120.1		217.9
120.2		101.4
120.3		68.30
125		4.310

TABLE III: $\ell^+\ell^- \rightarrow h$ cross sections for $M_h = 120$ GeV. The Muon Collider $\mu^+\mu^- \rightarrow h$ s-channel Higgs production has significantly higher cross section.

24	$\ell^+\ell^- \rightarrow Zh$	
	$\sigma (fb)$	
\sqrt{s}	e^+e^-	$\mu^+\mu^-$
220	152.2	171.3
250	223.2	236.0
300	186.6	188.3
350	137.6	138.1
500		62.2

TABLE IV: $\ell^+\ell^- \rightarrow Zh$ cross sections are similar at the e^+e^- and $\mu^+\mu^-$ colliders.

ZZ Fusion		3 TeV	5 TeV
MSUB(I)		$\sigma (fb)$	
123	$\mu^+\mu^- \rightarrow \mu^+\mu^- h^0$	47.24	64.66
123	$\rightarrow \mu^+\mu^- h^0 \rightarrow \mu^+\mu^- \mu^+\mu^-$	0.0139	
123	$\rightarrow \mu^+\mu^- h^0 \rightarrow \mu^+\mu^- b \bar{b}$	32.73	

WW Fusion			
124	$\mu^+\mu^- \rightarrow \nu \bar{\nu} h^0$	463.9	601.3
124	$\rightarrow \nu \bar{\nu} h^0 \rightarrow \nu \bar{\nu} \mu^+\mu^-$	0.1332	
124	$\rightarrow \nu \bar{\nu} h^0 \rightarrow \nu \bar{\nu} b \bar{b}$	309.2	

TABLE V: ZZ and WW fusion cross sections. Nev = 100 x the above numbers, for $L = 10^{34}$ and $10^7 sec/year$

<i>h @ Muon Collider</i>	125 GeV	3 TeV	5 TeV
		(fb)	
• $h\mu$ coupling	$\mu^+\mu^- \rightarrow h$	43000	
• h self-coupling	$\mu^+\mu^- \rightarrow hh\nu\nu$		1.9

At 3 TeV or 5 TeV, for $L = 10^{34}$ and $10^7 sec/year$, Nev/yr = 100 x the cross section (fb) numbers.

IV. $\mu^+ \mu^- \rightarrow h \rightarrow b\bar{b}$

The s-channel h production $\mu^+ \mu^- \rightarrow h$ would decay into $\rightarrow b\bar{b}$ with branching ratio of $\approx 60\%$ for $M_h = 125$ GeV. The background is $\mu^+ \mu^- \rightarrow Z$ with $Z \rightarrow b\bar{b}$ branching ratio of 15%. The Energy or the invariant mass of the $b\bar{b}$ for jet energy resolutions $\sigma(E)/\sqrt{(E)}$ of 30%, 50%, 70% are shown in Figure ???. Energy of b and \bar{b} reconstructed from 2 jets, with Energy ≥ 115 GeV, for energy resolutions of $30\%/\sqrt{E}$, $50\%/\sqrt{E}$ for h , Z events are shown in Figure ???, and are the signal $h \rightarrow b\bar{b}$ and background $Z \rightarrow b\bar{b}$ for $\mu^+ \mu^-$ at $\sqrt{s} = 125$ GeV.

$\mu^+ \mu^- \rightarrow h \text{ or } Z$							
Energy	$M_H - 3\sigma_E$	$M_H - 2\sigma_E$	$M_H - 1\sigma_E$	M_H Peak	$M_H + 1\sigma_E$	$M_H + 2\sigma_E$	$M_H + 3\sigma_E$
$\sigma(pb)$	1.048	1.996	4.700	9.634	7.793	4.129	2.491
	0.617	1.204	2.802	5.955	4.656	2.414	1.474
$\sigma h \rightarrow b\bar{b}$	0.617	1.204	2.802	5.955	4.656	2.414	1.474
$\sigma Z \rightarrow b\bar{b}$ 30%	52.24	52.29	51.98	52.03	52.66	52.52	51.97
$\sigma Z \rightarrow b\bar{b}$ 50%	18.01	18.01	18.00	18.00	18.02	18.02	18.00
100 pb $^{-1}$							
S							
N		120	280	596	466	241	
$\sqrt{S+N}$				1800			
$\sqrt{S+N}/S$				49			
$\sqrt{S+N}/S$				8.2%			
1000 pb $^{-1}$							
S				5960			
N				18000			
$\sqrt{S+N}$				155			
$\sqrt{S+N}/S$				2.6%			

TABLE VI: $\mu^+ \mu^- \rightarrow h \text{ or } Z$ at $\sqrt{s} = 125 \pm n\sigma_E$ GeV
 $\sigma_E = 0.003\% \times 125$ GeV

$\mu^+ \mu^- \rightarrow h$											
Energy $M_h + n \times$ MeV	-5	-4	-3	-2	-1	M_H	+1	+2	+3	+4	+5
100 pb $^{-1}$											
S	207	268	331	429	520	596	629	591	520	442	373
N						1800					
$\sqrt{S+N}$	45					49					
$\sqrt{S+N}/S$						8.2%					

TABLE VII: $\mu^+ \mu^- \rightarrow h \text{ or } Z$ at $\sqrt{s} = 125$ GeV $\pm n$ MeV
 $\sigma_E = 0.003\% \times 125$ GeV

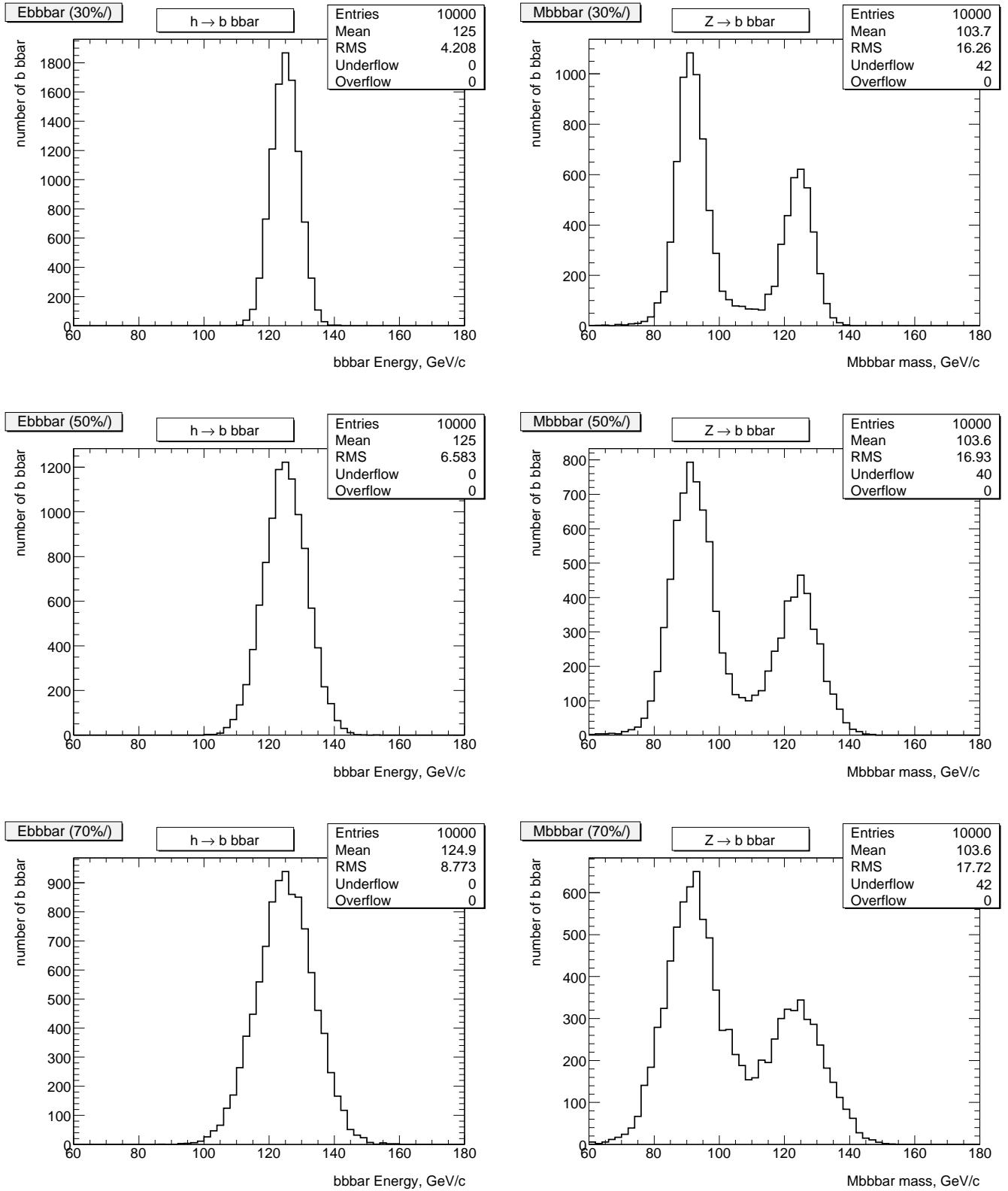


FIG. 3: Energy of b and \bar{b} reconstructed from 2 jets, for energy resolutions of 30%, 50%, 70% / \sqrt{E} for h , Z events

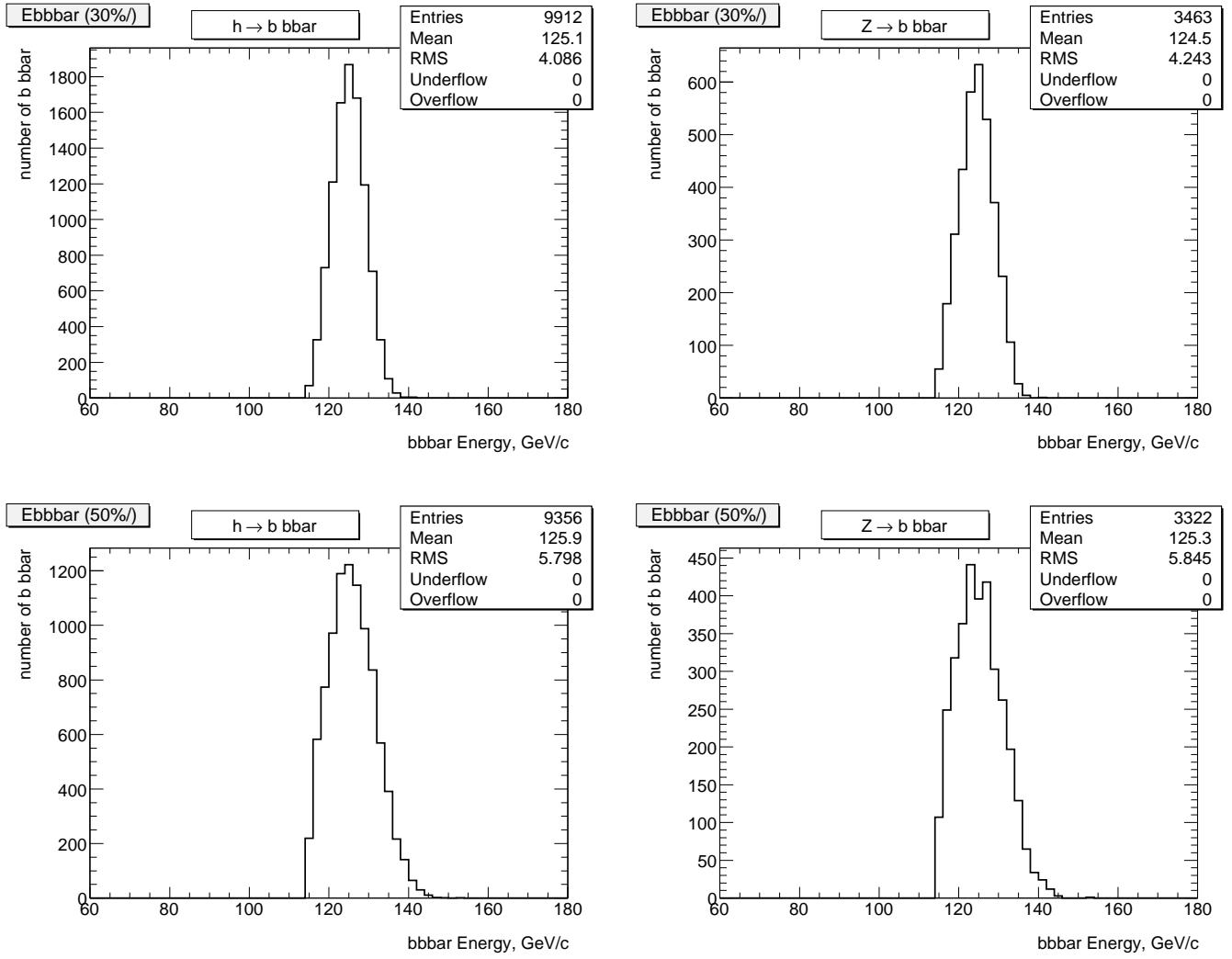


FIG. 4: Energy of b and \bar{b} reconstructed from 2 jets, with $\text{Energy} \geq 115 \text{ GeV}$, for energy resolutions of 30%, 50%, / \sqrt{E} for h, Z events

V. $\mu^+\mu^- \rightarrow h \rightarrow W^+W^-$

The s-channel h production $\mu^+\mu^- \rightarrow h \rightarrow W^+W^-$ has the 3 decay modes: DiLepton + no jets $W^+W^- \rightarrow \ell_1\nu_1 \ell_2\nu_2$, Lepton + 2 jets $W^+W^- \rightarrow \ell\nu j_1j_2$ and Multi-jets $W^+W^- \rightarrow j_1j_2 j_3j_4$. The $\mu^+\mu^- \rightarrow W^+W^-$ process is negligible at $\sqrt{s} = 125$ GeV, with $(\sigma(\mu^+\mu^- \rightarrow W^+W^-)) = 0.0463 pb$. The background would be $\mu^+\mu^- \rightarrow Z + jets$.

$$\mu^+\mu^- \rightarrow h \text{ (125 GeV)} \rightarrow W^+W^-$$

Energy	$M_H - 3\sigma_E$	$M_H - 2\sigma_E$	$M_H - 1\sigma_E$	M_H Peak	$M_H + 1\sigma_E$	$M_H + 2\sigma_E$	$M_H + 3\sigma_E$
100 pb^{-1}							
S	23	44	102	218	168	88	54
N				0			
$\sqrt{S+N}$			10	15	13		
$\sqrt{S+N}/S$				7%			

TABLE VIII: $\mu^+\mu^- \rightarrow h \rightarrow W^+W^-$ at $\sqrt{s} = 125 \pm n\sigma_E$ GeV
 $\sigma_E = 0.003\% \times 125$ GeV

1. DiLepton Channel $h \rightarrow W^+W^- \rightarrow \ell_1\nu_1 \ell_2\nu_2$

In the DiLepton Channel, each event to have 2 high P_T leptons ($e^+\mu^-, e^-\mu^+, e^+e^-, or \mu^+\mu^-$) and missing energy, with branching ratio of 4/81. The $e\mu$ channel is free from background events. The ee or $\mu\mu$ invariant and the missing energy are needed to separate the h signal from the $Z \rightarrow e^+e^-$ or $\mu^+\mu^-$ background.

2. Lepton + Jets Channel $h \rightarrow W^+W^- \rightarrow \ell\nu j_1j_2$

The invariant mass of the charged lepton and the missing energy will be shown in Figure XXX. Figure 5 shows M_w and M_w for jet energy resolutions of and $(30\%, 50\%, 60\%)/\sqrt{(E)} + 1\%$ for Top Quark events. Similarly, M_w for energy resolutions of 3%, 4%, 5%, 6%, for Top Quark events ins shown in Figure 8 Thus, the h signal can be distinguished from the Z background.

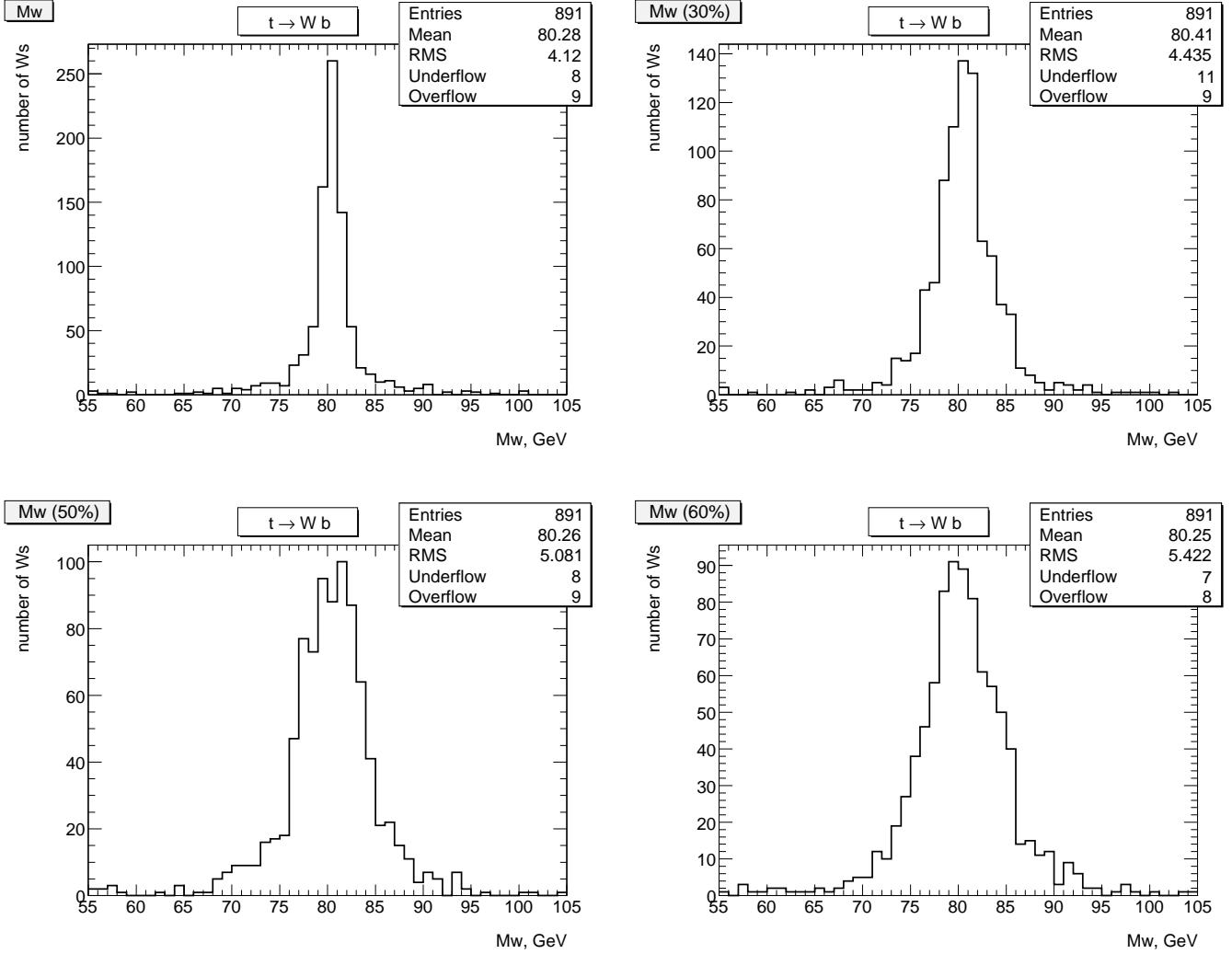


FIG. 5: M_w generated and M_w for jet energy resolutions of and $(30\%, 50\%, 60\%)/\sqrt{(E)} + 1\%$ for Top Quark events

VI. $\mu^+\mu^- \rightarrow h \rightarrow Z^0Z^0$

The Z^0 branching ratios 3.4% for e^+e^- , 3.4% for $\mu^+\mu^-$. The $\mu^+\mu^- \rightarrow h \rightarrow Z^0Z^0$ analysis may need to be studied with the $h \rightarrow Z^0Z^0 \rightarrow \ell\nu j_1j_2j_3j_4$ multi-channel to have enough statistics. The Lepton + 2 jets channel $h \rightarrow Z^0Z^0 \rightarrow \ell\ell j_1j_2$ and the DiLepton + no jets channel $h \rightarrow Z^0Z^0 \rightarrow \ell_1^+\ell_1^-\ell_2^+\ell_2^-$ may need more events to have enough statistics for analysis. The $\mu^+\mu^- \rightarrow Z^0Z^0$ process is negligible at $\sqrt{s} = 125$ GeV. The background would be $\mu^+\mu^- \rightarrow Z + jets$.

$\mu^+\mu^- \rightarrow h \text{ (125 GeV)} \rightarrow Z^0Z^0$							
Energy	$M_H - 3\sigma_E$	$M_H - 2\sigma_E$	$M_H - 1\sigma_E$	M_H Peak	$M_H + 1\sigma_E$	$M_H + 2\sigma_E$	$M_H + 3\sigma_E$
100 pb ⁻¹ S N $\sqrt{S+N}$	2.3	5.3	12.4	26.4 0 5	20.5	10.8	6.5

TABLE IX: $\mu^+\mu^- \rightarrow h \rightarrow Z^0Z^0$ at $\sqrt{s} = 125 \pm n\sigma_E$ GeV
 $\sigma_E = 0.003\% \times 125$ GeV

$$\mathbf{VII.} \quad \mu^+ \mu^- \rightarrow H^0, A^0, A^0 h^0, A^0 H^0, H^+ H^-$$

In MSSM, there are 5 Higgs particles $h^0 \ H^0 \ A^0 \ H^\pm$. At tree-level[14]:

$$m_{h^0, H^0}^{2(tree)} = \frac{1}{2} \left[m_A^2 + m_Z^2 \mp \sqrt{(m_A^2 + m_Z^2)^2 - 4m_A^2 m_Z^2 \cos^2 2\beta} \right]$$

$$m_{H^0}^2 + m_{h^0}^2 = m_A^2 + m_Z^2$$

At large m_A^0 , the masses $m_{H^0} \ m_{A^0} \ m_{H^\pm}$ are almost degenerate, as shown in Table XIII.

The Muon Collider could provide the large cross-sections for the $\mu^+ \mu^- \rightarrow A^0, h^0, H^0$ s-channel productions, and the fine beam energy spread and resolution helpful in event reconstruction and to measure the A^0, H^0, H^\pm degenerate masses.

A. Detector Resolutions

In the $\mu^+ \mu^- \rightarrow H^0, A^0, A^0 h^0, A^0 H^0, H^+ H^-$ Higgs and the $\mu^+ \mu^- \rightarrow H^0 \rightarrow \chi\chi$ chargino studies, it's important to distinguish $W \rightarrow q_i \bar{q}_j$ from $Z \rightarrow q\bar{q}$. Thus, jet Energy and Mass resolutions are important. Electron energy and Muon momentum are well measured. Detector for future lepton colliders are expected to have jet energy resolution of $30/\sqrt{E}$. The effects of jet energy resolution on W and Z separation can be studied using $\mu^+ \mu^- \rightarrow W^+ W^-$ or $Z^0 Z^0$ and $\mu^+ \mu^- \rightarrow \chi\chi$ Monte Carlo samples.

The effects of jet energy resolution on physics can also be studied for $t\bar{t}, t'\bar{t}'$, and $b'\bar{b}'$ samples. The precision beam energy calibration and resolution of the Muon Collider will be very important and helpful in event reconstruction and mass measurement. These subjects require long term studies.

Figure 6 shows WZ mass reconstructed from 2 jets, and WZ mass for jet energy resolutions of and (30%, 50%, 60%)/ \sqrt{E} + 1% for Top Quark events. Similarly, WZ mass reconstructed from 2 jets, and WZ mass for jet energy resolutions of for energy resolutions of 3%, 4%, 5%, 6%, for Top Quark events ins shown in Figure 9

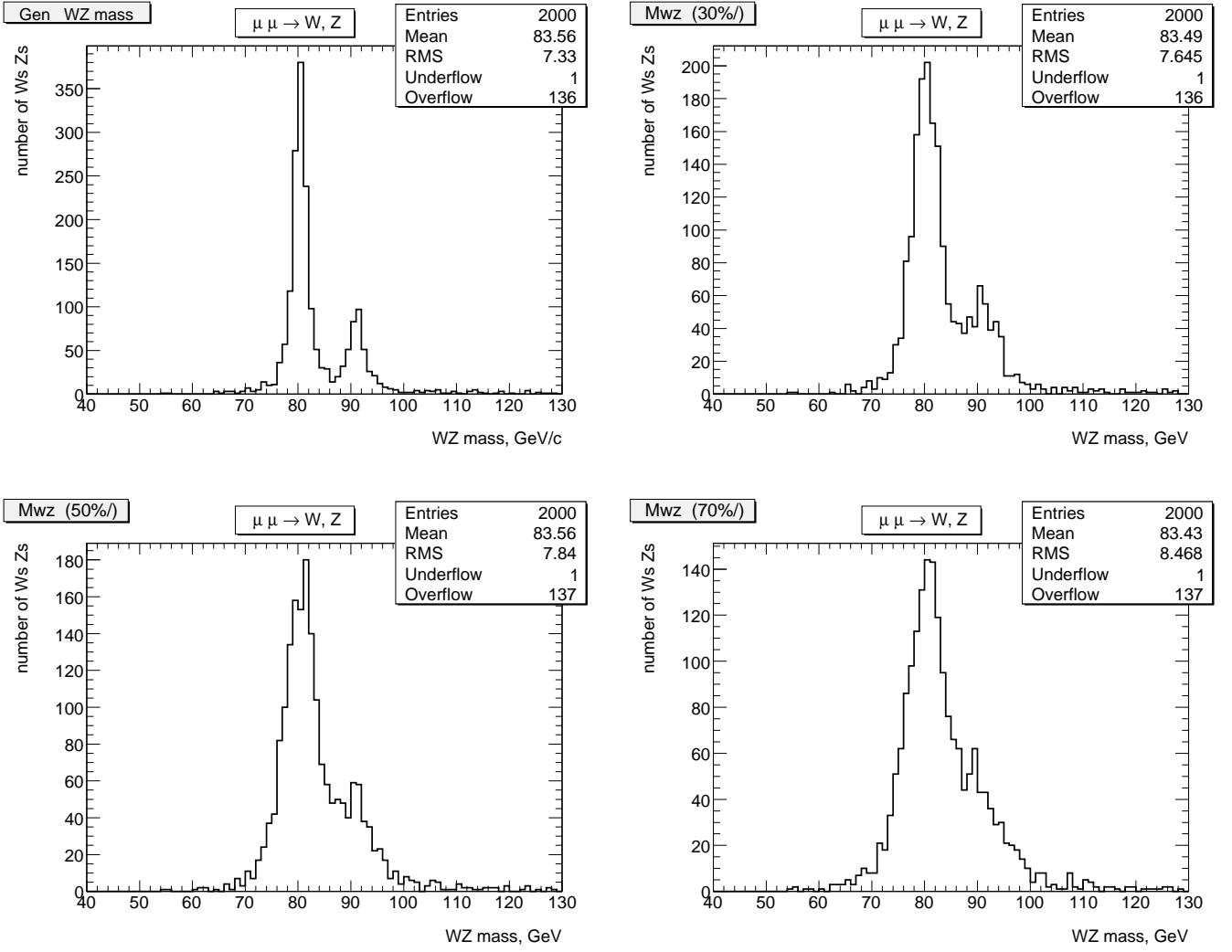


FIG. 6: WZ mass reconstructed from 2 jets, for energy resolutions of 30%, 50%, 70% / \sqrt{E} for W, Z events

VIII. BACKGROUNDS

	$\mu^+ \mu^- \rightarrow X \text{ (fb)}$						
\sqrt{s}	1000	1200	1500	2000	3000	4000	5000
$W^+ W^-$	3060	2370	1690	1140	672	465	359
$Z^0 Z^0$	217	172	123	80.1	42.4	28.5	19.9
$t \bar{t}$			93.9		25.8		

TABLE X: $\mu^+ \mu^- \rightarrow X$ cross sections from Pythia 6.4

\sqrt{s}	1000	1200	1500	2000	3000	4000	5000
$\nu\nu Z$	1000	1100	1300	1800	2300	2700	3000
$\nu\nu H(120)$	30	40	80	150	230	320	400
$\nu\nu WW$			320		400		
$ee WW$			43		130		
WW			1500		500		
$\nu\nu ZZ$			18		60		
$\nu\nu H(500)$			30		52		
$ee H(500)$			8		27		
WWZ			54		33		
ZZ			88		28		
$t\bar{t}$			88		21		
$\mu^+ \mu^-$			52		12		
$b\bar{b}$			42		11		
$\nu\nu HH(120)$			0.2	0.5	0.9	1.4	2
$t\bar{t}Z$			3.9		1.8		
$ZH(500)$			4.1		1.5		

TABLE XI: $\mu^+ \mu^- \rightarrow X$ cross sections from Battaglia, et al

\sqrt{s}	Other backgrounds			
	800 GeV	1000 GeV [[9]]	1500 GeV	3000 GeV
$q\bar{q}$	1560			
$t\bar{t}$	297			
$tbW \rightarrow bWbW$		250		
WW	4298			
ZZ	240			
$W^+ W^- Z^0 \rightarrow W^+ W^- b\bar{b}$			8	5
$t\bar{t}Z \rightarrow t\bar{t}b\bar{b}$	4.3	5		
$t\bar{t}g^* \rightarrow t\bar{t}b\bar{b}$		1.3		
$t\bar{t}h \rightarrow t\bar{t}b\bar{b}$	2.5	2.4		

TABLE XII: Other background cross sections.

IX. SUMMARY

The Higgs particle with 125 GeV mass should soon be discovered or ruled out by CMS and Atlas experiments at the LHC. The ILC, CLIC, and SLHC studies are trying to estimate the Higgs physics that can be achieved.

The Muon Collider has significant advantages for Higgs physics studies: 1) s-channel Higgs production : The $\ell^+ \ell^- \rightarrow h$ s-channel production rate is proportional to m_ℓ^2 , so that the production cross section at the Muon Collider is 40,000 times higher than the ILC or CLIC. 2) The high precision fixed beam energy of the Muon Collider provides important information about the incoming muons and kinematic constraints for physics analyses. Because of the heavier mass of muons relative to electrons, the Muon Collider has significantly less beamstrahlung and beam-beam effects than ILC or CLIC. 3) The circular ring naturally favors 2 interactions and 2 detectors, which effectively increase the luminosity, in contrast to linear colliders ILC or CLIC.

Because the width of the Higgs particle Γ_h is ≈ 4 MeV for $M_h = 125$ GeV, the beam energy spread needs to be $\approx 0.003\%$ at ≈ 125 GeV, which is possible according to Muon Collider experts David Neuffer and Vladimir Shiltsev. For beam energy spread $\approx 0.003\%$ at the Muon Collider, the mass and width of the Higgs particle with $M_h \approx 125$ GeV can be determined to an accuracy at the MeV level. Similarly, the s-channel production and the narrow beam energy spread and high precision would be excellent for studying the Supersymmetry Higgs particles H^0 and A^0 , which would be expected to have near degenerate masses. The best place to study the Standard Model or Supersymmetry Higgs particles if they exist, may be the Muon Collider.

X. ACKNOWLEDGMENTS

Thanks to Steve Mrenna for his Pythia generation and analysis example software, and for his help to me in starting these studies.

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Federico von der Pahlen, CPNSH4, CERN, 14.12.2005
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Neutralinos from Chargino Decays in the Complex MSSM
S. Heinemeyer, F. v. d. Pahlen and C. Schappacher
Instituto de Fisica de Cantabria (CSIC-UC) E39005 Santander, Spain
Karlsruhe Institute of Technology, Germany
<http://arxiv.org/abs/1202.0488>
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<http://arxiv.org/abs/1112.0760> Chargino Production at a future LC in the MSSM with complex Parameters: NLO Corrections Aoife Bharucha <http://arxiv.org/abs/1202.6284>
Chargino Neutralino & Higgs at Muon Collider
<http://janaganamana.net/getArticles.aspx?jgmsearch=Federico+von+der+Pahlen>
Karlsruhe Preprints * <http://de.arxiv.org/abs/1202.0488v1>
F. v. d. Pahlen et al
<http://www-itp.particle.uni-karlsruhe.de/prep2012.en.shtml>

XII. APPENDIX A

make pythiaExample

```

<detsim.fnal.gov>      $HOME/example/pythiaExample.F          Fortran file
                           initializes Beam Particles :      beam    mu+
                                         Beam Energy :           target   mu-
                                         reads in Pythia parameters from .card   file

cd $HOME/software/stdhep/
make clean
make

cd $HOME/software/pythia
make clean
make

cd $HOME/example
make pythiaExample

=====
Input parameters at Run time
=====

SEL=0
MSUB(1)=1

MDME(189,1)=1      ! Z -> nu_tau' decay code
23:ONIFMATCH 18 18 ! Z -> nu_tau'

MDME(???,1)=1      ! H+-

2                  ! 1 for e+ e-    2 for mu+ mu-
1400.0             ! cms Energy
0.01               ! rms delta_E / E (%)
2.0                ! x rms + cms Energy = Emax
43509876           ! seed for Pythia & RNDM random numbers
PMAS(25,1)=125.0   ! mass of Higgs
MSEL=0              ! MSTP(125)=0 List only particles actually produced
MSUB(22)=1          ! Z Z   use MSTP(43) to turn OFF gamma gamma
MSUB(25)=1          ! W+ W-
MSTP(43)=2          ! 1 gamma,  2 Z,   D=3 both
23:ALLOFF
23:ONIFMATCH 1 1
23:ONIFMATCH 2 2
23:ONIFMATCH 3 3
23:ONIFMATCH 4 4

```

```

2           ! 1 for e+ e-    2 for mu+ mu-
800.0       ! cms Energy
0.01        ! rms delta_E / E (%)
0.0          ! x rms + cms Energy = Emax
435019876   ! seed for Pythia & RNDM random numbers
MSEL=0       ! full user control
PMAS(25,1)=125.      ! h
PMAS(36,1)=800.      ! A0
MSUB(156)=1         ! A0
IMSS(1) = 1          ! user sets SUSY parameters
IMSS(4) = 1          ! SUSY radiatively corrected, set by MA
RMSS(1) = 100.        ! M1
RMSS(2) = 200.        ! M2
RMSS(3) = 1000.       ! M3
RMSS(4) = -200.       ! mu      higgsino mass  mu
RMSS(5) = 10.          ! tan(beta)
RMSS(19) = 800.        ! M_A
1000037:ALLOFF
1000037:ONIFMATCH 1000024 23      ! chi_2+  ->  chi_1+  Z
1000024:ALLOFF
1000024:ONIFMATCH 1000022 24      ! chi_1+  ->  chi_10  W

```

Run `pythiaExample` to generate Pythia events

```

export PYTHIA_CARD=PYTHIA6_bPrime_M600_E1250.card
export NUMBER_OF_EVENTS=10
./pythiaExample

export PYTHIA_CARD=PYTHIA6_TPrime2BPrime2Top_M600_E1250.card
export NUMBER_OF_EVENTS=1000
./pythiaExample

export PYTHIA_CARD=PYTHIA6_Tprime_M600_E1250.card
export NUMBER_OF_EVENTS=1000
./pythiaExample

export PYTHIA_CARD=PYTHIA6_TQ_E1250.card
export NUMBER_OF_EVENTS=1000
./pythiaExample

<detsim.fnal.gov>  ls -lt PYTHIA6*_E1250.*
1629559  PYTHIA6_TQ_E1250.lpt
27664360  PYTHIA6_TQ_E1250.io
1619310  PYTHIA6_Tprime_M600_E1250.lpt
26992848  PYTHIA6_Tprime_M600_E1250.io
2321917  PYTHIA6_TPrime2BPrime2Top_M600_E1250.lpt
44240316  PYTHIA6_TPrime2BPrime2Top_M600_E1250.io
452  PYTHIA6_TQ_E1250.card
313  PYTHIA6_Tprime_M600_E1250.card
377  PYTHIA6_TPrime2BPrime2Top_M600_E1250.card
1925824  PYTHIA6_bPrime_M600_E1250.lpt
34428720  PYTHIA6_bPrime_M600_E1250.io
503  PYTHIA6_bPrime_M600_E1250.card

```

Pythia run/control parameter .card files

Examples in: /sim1/home2/misc1/mrenna/muc/files/

PYTHIA6_SM_H_Fusion_mH120.card

```

2           ! 1 for e+ e-    2 for mu+ mu-
3000.0      ! cms Energy
PMAS(25,1)=120.0   ! mass of Higgs
MSEL=0       ! user selection for process
MSUB(123)=1   ! ZZ fusion to h
MSUB(124)=1   ! WW fusion to h

```

Ecms = 3000 fb

Mrenna

123	$\mu^+ \mu^- \rightarrow \mu^+ \mu^- h^0$	25.39
124	$\mu^+ \mu^- \rightarrow \nu \bar{\nu} h^0$	249.9

Extended neutral Higgs $h^0 \ H^0 \ A^0 \ H^\pm$

In MSSM, 5 Higgs particles $h^0 \ H^0 \ A^0 \ H^\pm$. At tree-level :

$$m_{h^0, H^0}^{2(tree)} = \frac{1}{2} \left[m_A^2 + m_Z^2 \mp \sqrt{(m_A^2 + m_Z^2)^2 - 4m_A^2 m_Z^2 \cos^2 2\beta} \right]$$

$$m_{H^0}^2 + m_{h^0}^2 = m_A^2 + m_Z^2$$

At large m_A^0 , the masses $m_{H^0} \ m_{A^0} \ m_{H^\pm}$ are almost degenerate.

Higgs Mass (GeV)				
$\tan\beta$	M_A	M_h^0	M_H^0	M_H^\pm
5	200	82.648	203.674	215.518
5	800	84.084	800.777	804.020
10	200	88.924	201.013	215.518
10	800	89.351	800.206	804.020
20	200	90.607	200.260	215.518
20	800	90.719	800.052	804.020
40	200	91.036	200.065	215.518
40	800	91.065	800.013	804.020

TABLE XIII: $A^0 \ h^0 \ H^0 \ H^\pm$ masses

The Muon Collider could provide the large cross-sections for the $\mu^+ \mu^- \rightarrow A^0, h^0, H^0$ s-channel productions, and fine beam energy spread and resolution to disentangle the degenerate masses.

151	$\mu^+ \mu^- \rightarrow H^0$	abc.d
156	$\mu^+ \mu^- \rightarrow A^0$	abc.d
173	$\mu^+ \mu^- \rightarrow \mu^+ \mu^- \ H^0$???
174	$\mu^+ \mu^- \rightarrow \nu \bar{\nu} \ H^0$???
178	$\mu^+ \mu^- \rightarrow \mu^+ \mu^- \ A^0$???
179	$\mu^+ \mu^- \rightarrow \nu \bar{\nu} \ A^0$???

Higgs pairs

299	$\mu^+ \mu^- \rightarrow A^0 h^0$	0.000077	0.000037
300	$\mu^+ \mu^- \rightarrow A^0 H^0$	0.832	0.535
301	$\mu^+ \mu^- \rightarrow H^+ H^-$	1.904	1.099

MSEL	changed from	1 to	0
PMAS(25,1)	changed from	115.00000 to	125.00000
PMAS(36,1)	changed from	300.00000 to	800.00000
MSUB(156)	changed from	0 to	1
IMSS(1)	changed from	0 to	1
IMSS(4)	changed from	1 to	1
RMSS(1)	changed from	80.00000 to	100.00000
RMSS(2)	changed from	160.00000 to	200.00000
RMSS(3)	changed from	500.00000 to	1000.00000
RMSS(4)	changed from	800.00000 to	-200.00000
RMSS(5)	changed from	2.00000 to	30.00000
RMSS(19)	changed from	850.00000 to	800.00000
Decays for 1000037	set ALLOFF		
Decays for 1000037	set ONIFMATCH if match 1000024	23	
Decays for 1000024	set ALLOFF		
Decays for 1000024	set ONIFMATCH if match 1000022	24	

I	I	I	I	I
I	Subprocess	I	Number of points	I
I		I		I
I-----	I-----	I-----	I-----	(mb) I
I		I		I
I N:o Type	I	Generated	Tried I	I
I	I		I	I
I	I	I	I	I
I	0 All included subprocesses	I	1000	10932 I 9.978D-10 I
I	156 f + fbar -> A0	I	1000	10932 I 9.978D-10 I
I		I	I	I

Z W T Masses	91.188	80.450	175.000	
M1,M2,M3,mu	100.000	200.000	1000.000	-200.000
Tan(Beta), MA	30.000	800.000		
Higgs Masses	112.536	799.914	799.514	804.177
Higgs Widths	0.003	22.981	22.970	18.983
H decay modes	79	86	83	27

H0 Decays	0.562	5	-5	b	bbar
H0 Decays	0.066	15	-15	tau-	tau+
H0 Decays	0.010	1000022	1000022	~chi_10	~chi_10
H0 Decays	0.031	1000023	1000022	~chi_20	~chi_10
H0 Decays	0.018	1000023	1000023	~chi_20	~chi_20
H0 Decays	0.015	1000025	1000022	~chi_30	~chi_10
H0 Decays	0.043	1000035	1000025	~chi_40	~chi_30
H0 Decays	0.015	1000035	1000035	~chi_40	~chi_40
H0 Decays	0.100	1000024	-1000024	~chi_1+	~chi_1-
H0 Decays	0.053	1000024	-1000037	~chi_1+	~chi_2-
H0 Decays	0.053	1000037	-1000024	~chi_2+	~chi_1-
H0 Decays	0.018	1000037	-1000037	~chi_2+	~chi_2-
A0 Decays	0.562	5	-5	b	bbar
A0 Decays	0.066	15	-15	tau-	tau+
A0 Decays	0.031	1000023	1000022	~chi_20	~chi_10
A0 Decays	0.020	1000023	1000023	~chi_20	~chi_20
A0 Decays	0.016	1000025	1000022	~chi_30	~chi_10
A0 Decays	0.031	1000035	1000025	~chi_40	~chi_30
A0 Decays	0.022	1000035	1000035	~chi_40	~chi_40
A0 Decays	0.109	1000024	-1000024	~chi_1+	~chi_1-
A0 Decays	0.045	1000024	-1000037	~chi_1+	~chi_2-
A0 Decays	0.045	1000037	-1000024	~chi_2+	~chi_1-
A0 Decays	0.026	1000037	-1000037	~chi_2+	~chi_2-
H+ Decays	0.469	-5	6	bbar	t
H+ Decays	0.080	-15	16	tau+	nu_tau
H+ Decays	0.058	1000022	1000024	~chi_10	~chi_1+
H+ Decays	0.161	1000023	1000037	~chi_20	~chi_2+
H+ Decays	0.060	1000025	1000024	~chi_30	~chi_1+
H+ Decays	0.062	1000025	1000037	~chi_30	~chi_2+
H+ Decays	0.097	1000035	1000024	~chi_40	~chi_1+

~chi_n0 Masses	94.073	155.868	211.859	261.919		
~chi_j+ Masses	153.490	263.410				
~chi_n0 Widths	0.00000	0.00002	0.05090	0.50422		
~chi_j+ Widths	0.00014	0.35073				
~chi_1+ KF =	1000024	KC = 312	MASS = 153.5			
~chi_1+ Decays	0.107	1000022	-11	~chi_10	e+	
~chi_1+ Decays	0.107	1000022	-13	~chi_10	mu+	
~chi_1+ Decays	0.107	1000022	-15	~chi_10	tau+	
~chi_1+ Decays	0.340	1000022	-1	~chi_10	dbar	
~chi_1+ Decays	0.340	1000022	-3	~chi_10	sbar	
~chi_2+ KF =	1000037	KC = 315	MASS = 263.4			
~chi_2+ Decays	0.220	1000024	23	~chi_1+	Z0	
~chi_2+ Decays	0.064	1000022	24	~chi_10	W+	
~chi_2+ Decays	0.545	1000023	24	~chi_20	W+	
~chi_2+ Decays	0.044	1000012	-11	~nu_eL	e+	
~chi_2+ Decays	0.021	-1000011	12	~e_L+	nu_e	
~chi_2+ Decays	0.044	1000014	-13	~nu_muL	mu+	
~chi_2+ Decays	0.021	-1000013	14	~mu_L+	nu_mu	
~chi_2+ Decays	0.039	1000016	-15	~nu_tauL	tau+	
~chi_20 KF =	1000023	KC = 311	MASS = 155.9			
~chi_20 Decays	0.012	1000022	15	~chi_10	tau-	
~chi_20 Decays	0.034	1000022	12	~chi_10	nu_e	
~chi_20 Decays	0.034	1000022	14	~chi_10	nu_mu	
~chi_20 Decays	0.036	1000022	16	~chi_10	nu_tau	
~chi_20 Decays	0.190	1000022	1	~chi_10	d	
~chi_20 Decays	0.190	1000022	3	~chi_10	s	
~chi_20 Decays	0.190	1000022	5	~chi_10	b	
~chi_20 Decays	0.148	1000022	2	~chi_10	u	
~chi_20 Decays	0.148	1000022	4	~chi_10	c	
~chi_30 KF =	1000025	KC = 313	MASS = -211.9			
~chi_30 Decays	0.882	1000022	23	~chi_10	Z0	
~chi_30 Decays	0.012	1000022	25	~chi_10	h0	
~chi_30 Decays	0.037	1000015	-15	~tau_1-	tau+	
~chi_30 Decays	0.037	-1000015	15	~tau_1+	tau-	
~chi_40 KF =	1000035	KC = 314	MASS = 261.9			
~chi_40 Decays	0.027	1000022	23	~chi_10	Z0	
~chi_40 Decays	0.059	1000022	25	~chi_10	h0	
~chi_40 Decays	0.376	1000024	-24	~chi_1+	W-	
~chi_40 Decays	0.376	-1000024	24	~chi_1-	W+	
~chi_40 Decays	0.023	1000012	-12	~nu_eL	nu_ebar	
~chi_40 Decays	0.023	-1000012	12	~nu_eLbar	nu_e	
~chi_40 Decays	0.023	1000014	-14	~nu_muL	nu_mubar	
~chi_40 Decays	0.023	-1000014	14	~nu_muLbar	nu_mu	
~chi_40 Decays	0.016	1000016	-16	~nu_tauL	nu_taubar	
~chi_40 Decays	0.016	-1000016	16	~nu_tauLbar	nu_tau	

MSEL	changed from	1 to	0
PMAS(25,1)	changed from	115.00000 to	125.00000
PMAS(36,1)	changed from	300.00000 to	800.00000
MSUB(156)	changed from	0 to	1
IMSS(1)	changed from	0 to	1
IMSS(4)	changed from	1 to	1
RMSS(1)	changed from	80.00000 to	100.00000
RMSS(2)	changed from	160.00000 to	200.00000
RMSS(3)	changed from	500.00000 to	1000.00000
RMSS(4)	changed from	800.00000 to	-200.00000
RMSS(5)	changed from	2.00000 to	10.00000
RMSS(19)	changed from	850.00000 to	800.00000
Decays for 1000037	set ALLOFF		
Decays for 1000037	set ONIFMATCH if match 1000024	23	
Decays for 1000024	set ALLOFF		
Decays for 1000024	set ONIFMATCH if match 1000022	24	

I	I	I	I	I
I	Subprocess	I	Number of points	I
I		I		I
I-----	I-----	I-----	I-----	I-----
I				(mb)
I			I	I
I N:o Type		I	Generated	Tried I
I		I		I
I	I	I	I	I
I	0 All included subprocesses	I	1000	10993 I 1.266D-10 I
I	156 f + fbar -> A0	I	1000	10993 I 1.266D-10 I
I		I		I

Z W T Masses	91.188	80.450	175.000	
M1,M2,M3,mu	100.000	200.000	1000.000	-200.000
Tan(Beta), MA	10.000	800.000		
Higgs Masses	111.356	800.164	799.840	803.841
Higgs Widths	0.003	10.002	10.050	10.191
H decay modes	79	86	83	27

H0 Decays	0.119	5	-5	b	bbar
H0 Decays	0.028	6	-6	t	tbar
H0 Decays	0.017	15	-15	tau-	tau+
H0 Decays	0.019	1000022	1000022	~chi_10	~chi_10
H0 Decays	0.074	1000023	1000022	~chi_20	~chi_10
H0 Decays	0.053	1000023	1000023	~chi_20	~chi_20
H0 Decays	0.026	1000025	1000022	~chi_30	~chi_10
H0 Decays	0.013	1000025	1000023	~chi_30	~chi_20
H0 Decays	0.007	1000025	1000025	~chi_30	~chi_30
H0 Decays	0.009	1000035	1000023	~chi_40	~chi_20
H0 Decays	0.089	1000035	1000025	~chi_40	~chi_30
H0 Decays	0.041	1000035	1000035	~chi_40	~chi_40
H0 Decays	0.246	1000024	-1000024	~chi_1+	~chi_1-
H0 Decays	0.103	1000024	-1000037	~chi_1+	~chi_2-
H0 Decays	0.103	1000037	-1000024	~chi_2+	~chi_1-
H0 Decays	0.052	1000037	-1000037	~chi_2+	~chi_2-
A0 Decays	0.119	5	-5	b	bbar
A0 Decays	0.032	6	-6	t	tbar
A0 Decays	0.017	15	-15	tau-	tau+
A0 Decays	0.017	1000022	1000022	~chi_10	~chi_10
A0 Decays	0.063	1000023	1000022	~chi_20	~chi_10
A0 Decays	0.046	1000023	1000023	~chi_20	~chi_20
A0 Decays	0.038	1000025	1000022	~chi_30	~chi_10
A0 Decays	0.021	1000025	1000023	~chi_30	~chi_20
A0 Decays	0.014	1000025	1000025	~chi_30	~chi_30
A0 Decays	0.011	1000035	1000023	~chi_40	~chi_20
A0 Decays	0.078	1000035	1000025	~chi_40	~chi_30
A0 Decays	0.040	1000035	1000035	~chi_40	~chi_40
A0 Decays	0.233	1000024	-1000024	~chi_1+	~chi_1-
A0 Decays	0.114	1000024	-1000037	~chi_1+	~chi_2-
A0 Decays	0.114	1000037	-1000024	~chi_2+	~chi_1-
A0 Decays	0.042	1000037	-1000037	~chi_2+	~chi_2-
H+ Decays	0.129	-5	6	bbar	t
H+ Decays	0.016	-15	16	tau+	nu_tau
H+ Decays	0.112	1000022	1000024	~chi_10	~chi_1+
H+ Decays	0.013	1000023	1000024	~chi_20	~chi_1+
H+ Decays	0.309	1000023	1000037	~chi_20	~chi_2+
H+ Decays	0.113	1000025	1000024	~chi_30	~chi_1+
H+ Decays	0.120	1000025	1000037	~chi_30	~chi_2+
H+ Decays	0.184	1000035	1000024	~chi_40	~chi_1+

~chi_n0 Masses		96.016	159.027	213.224	258.181	
~chi_j+ Masses		158.524	260.412			
~chi_n0 Widths		0.00000	0.00003	0.03814	0.35378	
~chi_j+ Widths		0.00015	0.24184			
~chi_1+ KF =	1000024	KC = 312	MASS = 158.5			
~chi_1+ Decays	0.102	1000022	-11	~chi_10	e+	
~chi_1+ Decays	0.102	1000022	-13	~chi_10	mu+	
~chi_1+ Decays	0.103	1000022	-15	~chi_10	tau+	
~chi_1+ Decays	0.346	1000022	-1	~chi_10	dbar	
~chi_1+ Decays	0.346	1000022	-3	~chi_10	sbar	
~chi_2+ KF =	1000037	KC = 315	MASS = 260.4			
~chi_2+ Decays	0.135	1000024	23	~chi_1+	Z0	
~chi_2+ Decays	0.135	1000022	24	~chi_10	W+	
~chi_2+ Decays	0.554	1000023	24	~chi_20	W+	
~chi_2+ Decays	0.050	1000012	-11	~nu_eL	e+	
~chi_2+ Decays	0.019	-1000011	12	~e_L+	nu_e	
~chi_2+ Decays	0.050	1000014	-13	~nu_muL	mu+	
~chi_2+ Decays	0.019	-1000013	14	~mu_L+	nu_mu	
~chi_2+ Decays	0.034	1000016	-15	~nu_tauL	tau+	
~chi_20 KF =	1000023	KC = 311	MASS = 159.0			
~chi_20 Decays	0.036	1000022	12	~chi_10	nu_e	
~chi_20 Decays	0.036	1000022	14	~chi_10	nu_mu	
~chi_20 Decays	0.038	1000022	16	~chi_10	nu_tau	
~chi_20 Decays	0.191	1000022	1	~chi_10	d	
~chi_20 Decays	0.191	1000022	3	~chi_10	s	
~chi_20 Decays	0.191	1000022	5	~chi_10	b	
~chi_20 Decays	0.149	1000022	2	~chi_10	u	
~chi_20 Decays	0.149	1000022	4	~chi_10	c	
~chi_30 KF =	1000025	KC = 313	MASS = -213.2			
~chi_30 Decays	0.942	1000022	23	~chi_10	Z0	
~chi_30 Decays	0.018	1000022	25	~chi_10	h0	
~chi_40 KF =	1000035	KC = 314	MASS = 258.2			
~chi_40 Decays	0.037	1000022	23	~chi_10	Z0	
~chi_40 Decays	0.084	1000022	25	~chi_10	h0	
~chi_40 Decays	0.353	1000024	-24	~chi_1+	W-	
~chi_40 Decays	0.353	-1000024	24	~chi_1-	W+	
~chi_40 Decays	0.025	1000012	-12	~nu_eL	nu_ebar	
~chi_40 Decays	0.025	-1000012	12	~nu_eLbar	nu_e	
~chi_40 Decays	0.025	1000014	-14	~nu_muL	nu_mubar	
~chi_40 Decays	0.025	-1000014	14	~nu_muLbar	nu_mu	
~chi_40 Decays	0.015	1000016	-16	~nu_tauL	nu_taubar	
~chi_40 Decays	0.015	-1000016	16	~nu_tauLbar	nu_tau	

Background processes

		3 TeV	5 TeV
???	$\mu^+ \mu^- \rightarrow \nu \bar{\nu} Z$	2100	3000
???	$\mu^+ \mu^- \rightarrow eeWW$???	
???	$\mu^+ \mu^- \rightarrow \nu \bar{\nu} WW$???	
???	$\mu^+ \mu^- \rightarrow \nu \bar{\nu} ZZ$???	
25	$\mu^+ \mu^- \rightarrow W^+ W^-$	671.9	359.6
???	$\mu^+ \mu^- \rightarrow WWZ$	31	20
22	$\mu^+ \mu^- \rightarrow ZZ$	42.19	19.87
???	$\mu^+ \mu^- \rightarrow \nu \bar{\nu} t \bar{t}$???	
81	$\mu^+ \mu^- \rightarrow b \bar{b}$	37.82	14.09
81	$\mu^+ \mu^- \rightarrow t \bar{t}$	25.34	9.523
???	$\mu^+ \mu^- \rightarrow \mu \mu$	23.90	9.041
???	$\mu^+ \mu^- \rightarrow \nu \bar{\nu} hh$	1.0	1.7
???	$\mu^+ \mu^- \rightarrow t \bar{t} Z$???	
24	$\mu^+ \mu^- \rightarrow Zh$	1.896	0.7224

$$\begin{array}{ll} \text{??? } \mu^+ \mu^- \rightarrow \mu^+ \mu^- \text{ } WW \rightarrow \mu^+ \mu^- \mu^+ \mu^- & \text{???} \\ \text{??? } \mu^+ \mu^- \rightarrow \nu \bar{\nu} \text{ } WW \rightarrow \nu \bar{\nu} \mu^+ \mu^- & \text{???} \end{array}$$

$$\begin{array}{ll} 1ab \quad \mu^+\mu^- \rightarrow \mu^+\mu^- X \rightarrow \mu^+\mu^- b \bar{b} & ??? \\ 1cd \quad \mu^+\mu^- \rightarrow \nu \bar{\nu} Y \rightarrow \nu \bar{\nu} b \bar{b} & ??? \end{array}$$

CLIC Benchmarks [10] [11]

Ecms = 3000			fb
123	$e^+e^- \rightarrow e^+e^- h^0$		47.24
123	$\rightarrow e^+e^- h^0 \rightarrow e^+e^- \mu^+\mu^-$		0.0139
123	$\rightarrow e^+e^- h^0 \rightarrow e^+e^- b \bar{b}$		32.73
124	$e^+e^- \rightarrow \nu \bar{\nu} h^0$		463.9
124	$\rightarrow \nu \bar{\nu} h^0 \rightarrow \nu \bar{\nu} \mu^+\mu^-$		0.1332
124	$\rightarrow \nu \bar{\nu} h^0 \rightarrow \nu \bar{\nu} b \bar{b}$		309.2
300	$e^+e^- \rightarrow H^0 A^0$??..??
301	$\rightarrow H^+ H^-$??..??
278	$e^+e^- \rightarrow \tilde{Q}_R \bar{\tilde{Q}}_R \rightarrow q \bar{q} \tilde{\chi}_1^0 \tilde{\chi}_1^0$??..??
	$e^+e^- \rightarrow \tilde{\ell}^+ \tilde{\ell}^-$??..??
205	$\rightarrow \tilde{\mu}_R^+ \tilde{\mu}_R^- \rightarrow \mu^+\mu^- \tilde{\chi}_1^0 \tilde{\chi}_1^0$??..??
202	$\rightarrow \tilde{e}_R^+ \tilde{e}_R^- \rightarrow e^+ e^- \tilde{\chi}_1^0 \tilde{\chi}_1^0$??..??
201	$\rightarrow \tilde{e}_L^+ \tilde{e}_L^- \rightarrow e^+ e^- \tilde{\chi}_2^0 \tilde{\chi}_2^0$??..??
213	$\rightarrow \tilde{\nu}_e \tilde{\nu}_e \rightarrow e^+ e^- W^+ W^- \tilde{\chi}_1^0 \tilde{\chi}_1^0$??..??
21x	$e^+e^- \rightarrow \tilde{\chi}_i^0 \tilde{\chi}_i^0$??..??
22y	$\rightarrow \tilde{\chi}_i^+ \tilde{\chi}_i^-$??..??
Ecms = 500			fb
81	$e^+e^- \rightarrow t \bar{t}$????

CLIC Cross Sections [12]

$\sigma(fb)$	3 TeV	5 TeV
$t\bar{t}$	20	7.3
$b\bar{b}$	11	3.8
ZZ	27	11
WW	490	205
hZ	1.4	0.5
$h\nu\nu$	230	390
$hh\nu\nu$	0.9	1.9
$H^+H^- (1TeV)$	1.5	1.0
$\tilde{\mu}^+\tilde{\mu}^- (1TeV)$	1.3	1.0

 TABLE XIV: CLIC e^+e^- cross sections. Nev = 100 x the above numbers, for $L = 10^{34}$ and $10^7 sec/year$

ILC Zh

$L = 0.7 \times 10^{34}$ @ 250 GeV
 $250 \text{ fb}^{-1} \approx 4 \text{ years of running.}$

$$(L = 1 \times 10^{34}) \times 10^7 \text{ sec/year} = 100 \text{ fb}^{-1} \text{ per year.}$$

$$\times (\sigma = 1 \text{ fb}) = 100 \text{ events per year.}$$

$$\sigma(e^+e^- \rightarrow Zh) = 265 \text{ fb} \quad \text{for } M_h = 120 \text{ GeV}$$

$$Br Z \rightarrow \nu\bar{\nu} = 20\%$$

$$Br Z \rightarrow e^+e^- = 3.4\%$$

LHC will measure branching ratios to 10 % level

ILC would measure branching ratios to few % level

Except :

- $Br h \rightarrow \mu\mu \approx 10^{-4}$
 $\mu^+\mu^- \rightarrow h$
- Higgs self-coupling

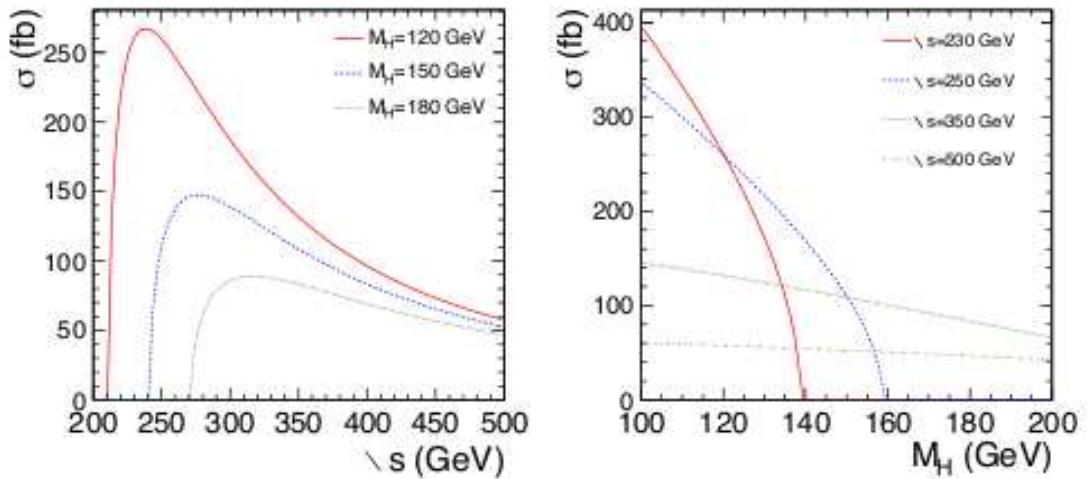


Figure 2.5: Cross-section (σ) of Higgs-strahlung process, as a function of center of mass energy (\sqrt{s}) (left) and as a function of Higgs mass (M_H) (right).

FIG. 7: ILC Zh cross sections [8]

```

run  pythiaExample  to generate  TPrime_M600  bPrime_M600 events

printenv ROOTSYS
gcc -v

cd
mkdir 4th
cd 4th
cp ..../example/GNUmakefile .
cp ..../example/pythiaExample.F .
make pythiaExample

cp ..../example/PYTHIA6_TPrime_M600.card .

export PYTHIA_CARD=PYTHIA6_TPrime_M600.card
export NUMBER_OF_EVENTS=1000
./pythiaExample

export PYTHIA_CARD=PYTHIA6_bPrime_M600.card
export NUMBER_OF_EVENTS=1000
./pythiaExample

export PYTHIA_CARD=PYTHIA6_TPrime2BPrime2Top_M600.card
export NUMBER_OF_EVENTS=1000
./pythiaExample

ls -lt *M600.lpt          ! ./pythiaExample printout events
ls -lt *M600.io            ! ./pythiaExample output event files

cd
source setup_root.sh

cd $HOME/ExRootAnalysis/MyAnalysis600

ls -lt ~gpyeh/example/*600.io   ! Convert .io --> .root
..../ExRootSTDHEPConverter ~gpyeh/example/PYTHIA6_bPrime_M600.io bPrime_M600_pythia.root
..../ExRootSTDHEPConverter ~gpyeh/example/PYTHIA6_TPrime_M600.io Tprime_M600_pythia.root
..../ExRootSTDHEPConverter ~gpyeh/example/PYTHIA6_TPrime2BPrime2Top_M600.io TPrime_M600_pythia.root

```

Pythia Generator Level Analysis

```

source setup_root.sh

cd $HOME/ExRootAnalysis/MyAnalysisRes

cp $HOME/ExRootAnalysis/MyAnalysis/GNUmakefile .

ls -lt *.root

cp Example_1_TP_Wbprime.cpp Example.cpp
make
example TPrime_M600_pythia.root

```

```
cp Example_2_Tp_Wb.cpp Example.cpp
make
example Tprime_M600_pythia.root

cp Example_3_bprime.cpp Example.cpp
make
example bPrime_M600_pythia.root

ls -lt *.png
display file_name. png

ls -lt *.eps
```

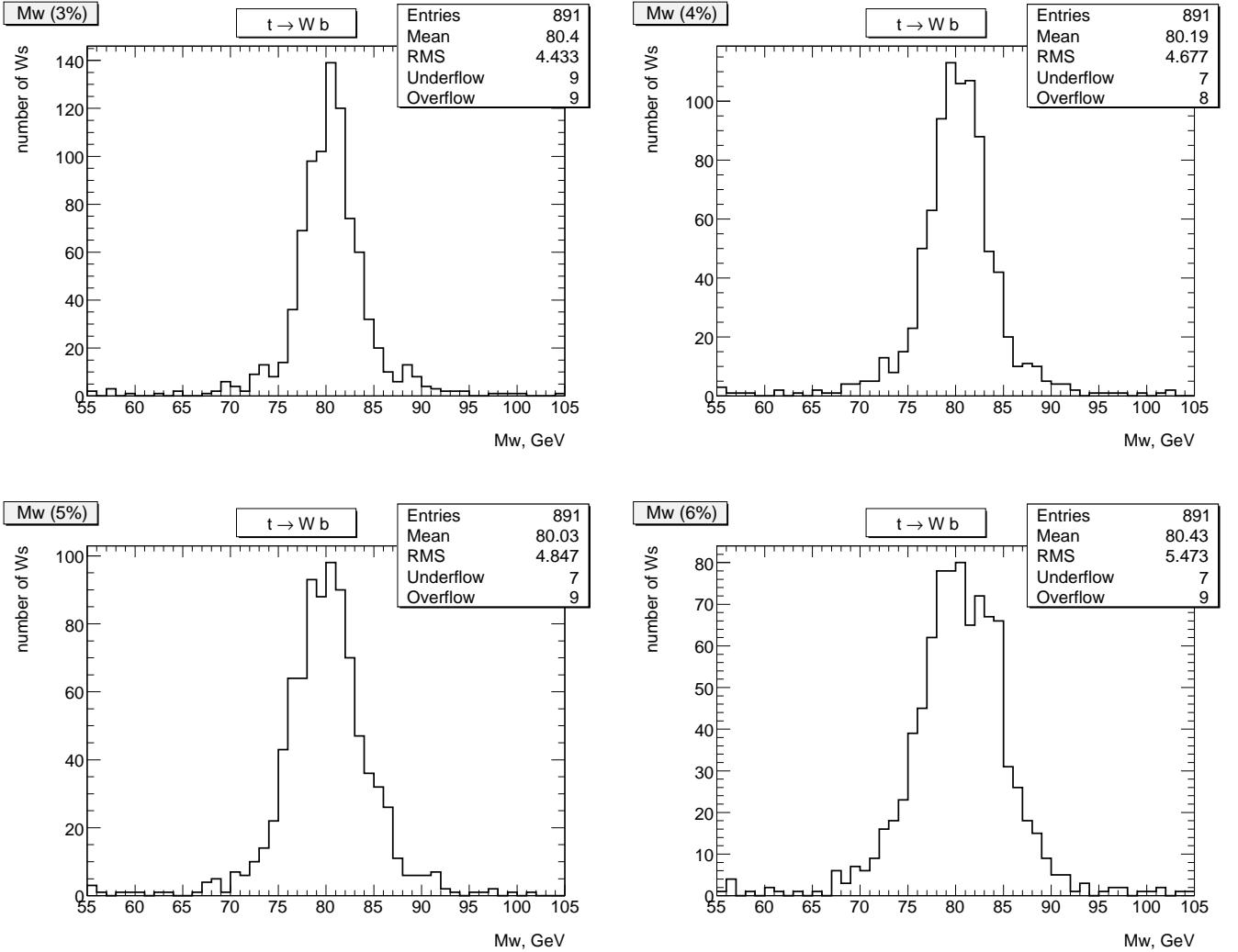


FIG. 8: M_w for energy resolutions of 3%, 4%, 5%, 6%, for Top Quark events

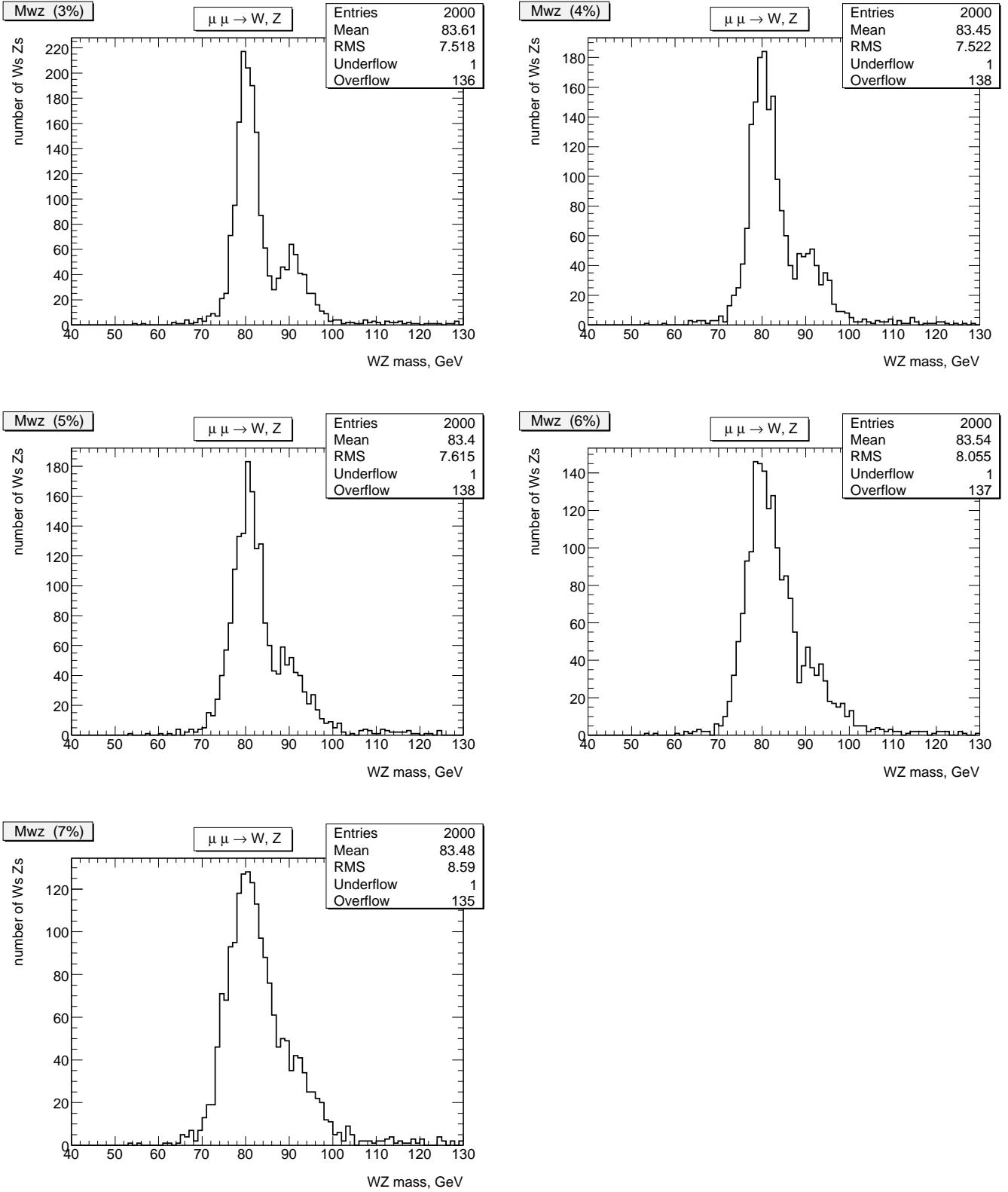


FIG. 9: WZ mass reconstructed from 2 jets, for energy resolutions of 3%, 4%, 5%, 6%, 7%, for W, Z events